

resistance measurements have been made between the mesh and near-by water pipes. So far as is known, none of the resistances exceeded 10 ohms; most of them were lower.

**Network protection.**—It is well known that fires may be started by lightning without occurrence of direct hits. A cloud-to-cloud discharge or a stroke to earth at some distance from an oil tank may cause sparks between isolated metal parts due to the release of the bound electrostatic charge.

For example, a thundercloud may have its charge gradually increased, by the breaking up of water drops falling through upward currents of air (Simpson, G. C., "On the electricity of rain and its origin in thunderstorms," *Phil. Trans. Roy. Soc. A* 209, 379, 1909. See also *Proc. Roy. Soc.* for April, 1927), or whatever process takes place, until the voltage approaches spark over. During the charging-up period, a charge of opposite sign builds up by induction on the earth below. At spark over (whether to another cloud, to another part of the same cloud, or to earth) the induced charge on the earth is released. It spreads out in all directions to get back to normal density. Sparks can occur during this rush only between isolated conductors or conductors in poor contact. A reservoir roof may have isolated metallic structures such as gauging wells, swing-pipe winch boxes, ventilators, etc., or it may have a combination of metal nailing strips, nails, and patches of condensate below the roofs with dangerous spark gaps.

All reservoir owners have inspected their reservoirs and have taken precautions against such conditions wherever possible. Metallic equipment and pipes have been interconnected and grounded. Roof structures well out from the edge have been grounded by No. 4 or No. 6 copper wires running down through the oil to the reinforcing mesh or over the reservoir bank to a water pipe.

Perfect protection against induced discharges may be obtained only by the use of all-metal roofs, with all joints well bonded. An approximation to an all-metal roof may be secured by the use of wire mesh or networks.

A system developed by Dr. E. R. Schaeffer, of Johns-Manville (Inc.), has been adopted by three Pacific coast companies. It has been placed on 32 reservoirs with a total capacity of 26,250,000 barrels and on a number of wooden-roof steel tanks. This method uses the electrostatic shielding effect of a system of grounded wires suspended over the roof. It is a development of the Faraday cage, based on the equations of Maxwell and on laboratory and field tests extending over several years.

The network used on reservoir roofs consists of No. 12 galvanized telephone wires, parallel, spaced 4 feet apart and 6 to 12 feet above the roof. The wires are supported by a  $\frac{3}{8}$ -inch peripheral cable carried on posts around the reservoir and by another cable crossing the roof on posts. Where the strength of the roof is not sufficient to carry the additional load, the center cable is suspended from a catenary. The network projects 16 feet beyond the rim at all points.

The network used on wooden roofs of steel tanks consists of an umbrella type grid supported by a single post 9 feet above the peak of the roof and by galvanized brackets spaced 15 feet apart around the rim. No. 12 galvanized wires radiate from the center post to the brackets with supplementary wires filling the wide gaps near the periphery so that the maximum spacing of wires is 5 feet.

On both reservoir and tank grids all wires are carefully bonded to the peripheral cable or tank brackets. The cables are grounded through their radial guys to water pipes or to a copper wire buried 12 inches and surrounding the reservoir.

The value of the network is due to the fact that it carries the induced charge, keeping it off the roof and affording good metallic paths to ground for its return after release. The percentage of the induced charge removed from the roof to the network is a function of the diameter and spacing of the wires, their height above the roof, and the cloud height. The arrangement adopted is one which is claimed to be an economical approximation of an all-metal roof.

**Prevention of lightning voltages.**—One company has adopted a system which it is claimed will prevent the formation of lightning voltages and therefore prevent both direct and induced discharges. The system consists of barbed wire strung on steel towers 80 to 100 feet high around each reservoir for the purpose of dissipating, by corona discharge, any induced charges in the area. The inventor, John M. Cage, of Los Angeles, claims that the charge of a thundercloud may be neutralized in this manner or kept below the sparking value. This system, which is described in detail in current petroleum journals (Wilcox, E. H., "Lightning protection system adopted to prevent, not guide, the stroke," *Nat. Pet. News*, March 9, 1927, p. 77; same author, "The cage system of lightning protection," *Oil Age*, March, 1927, p. 18), has been installed on six reservoirs with a total capacity of 12,500,000 barrels. Included in this group is the largest oil reservoir in the world. The reservoirs are used for fuel oil only.

## A COMPARISON OF AIR AND SOIL TEMPERATURES

By HARRY G. CARTER, Meteorologist

[Weather Bureau, Lincoln, Nebr.]

During the five years 1900 to 1904 a record was kept of the temperatures of the soil at depths of 1 inch, 3, 6, 9, 12, 24, and 36 inches at the Agricultural College of the University of Nebraska, at Lincoln. The thermometers were read once daily, at about dark. The data were tabulated and comparisons made with air temperatures as recorded by the United States Weather Bureau at the regular 6:45 p. m. observation at the city campus of the university, about 3 miles to the southwest.

The thermometers used in obtaining soil temperatures were standard soil thermometers. The scales from which the readings were made were made above ground so that the thermometers were not disturbed when read. The tube of each was inclosed in a closely fitting wooden cylinder which prevented air from passing down around it and also prevented the mercury in the tube from being affected by the surrounding soil. The bulb at the bottom was uncovered. The surface of the ground above the thermometer bulbs was kept free of grass and weeds over a rod square. The readings were made daily just before dark.

It was found that the temperature, for the year as a whole, averaged 54.9° in the air, and 58.2° in the soil at a depth of 1 inch. There was a decrease in annual temperature of the soil from 1 inch down to 12 inches, where it averaged 51.5°, then a slight increase down to 24 inches, where it averaged 52.2°. The average at 36 inches was the same as at 24 inches. For the whole year

the temperature of the soil at a depth somewhere between 6 and 9 inches averaged the same as the temperature of the air.

Table 1 gives the mean monthly and annual temperatures of the air and of the soil at the various depths at which readings were made.

TABLE 1.—Mean monthly and annual temperature of the air and of the soil at depths of 1 inch, 3, 6, 9, 12, 24, and 36 inches, at Lincoln, Nebr., for the 5 years 1900 to 1904, inclusive, as determined by considering one daily reading of the thermometers

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Air.....	29.2	25.1	42.8	56.5	67.8	75.6	82.7	79.1	68.4	60.7	42.5	28.8	54.9
Soil:													
1 inch.....	30.0	28.2	42.4	58.6	74.5	82.3	90.8	85.6	72.0	60.0	43.5	31.0	58.2
3 inches.....	30.0	28.7	41.1	59.3	72.1	81.2	88.6	85.3	72.9	61.4	44.3	31.6	58.0
6 inches.....	29.6	28.0	37.9	54.5	68.7	77.5	83.6	82.0	71.0	60.2	44.1	31.9	55.8
9 inches.....	30.0	28.4	35.7	50.8	64.4	73.0	79.4	77.9	70.5	59.0	44.3	33.4	53.9
12 inches.....	31.4	29.3	35.0	48.2	60.8	69.5	75.8	75.0	66.6	58.4	45.1	34.8	51.5
24 inches.....	35.1	32.9	34.7	44.8	56.5	64.2	70.8	71.6	66.9	59.7	49.5	39.5	52.2
36 inches.....	38.1	35.3	35.7	43.0	53.2	61.1	67.5	69.4	66.7	60.7	52.1	43.2	52.2

A study of Table 1 shows that the lowest mean monthly temperatures in the soil were recorded at all depths during February, and from 1 inch down to 12 inches the highest monthly means were recorded during July. At 24 and 36 inches there was a slight lag, the highest monthly means being recorded during August instead of July.

Air temperatures averaged lower than the temperature of the soil at all depths during the winter months and were higher than in the soil below 9 inches during spring, summer, and early autumn. At a depth of 1 inch the soil averaged warmer than the air, except during March and October. At 24 inches monthly means averaged above freezing throughout the year, although readings below 32° were observed several times.

During late fall and winter the temperature of the air averaged lower than that of the soil at a depth of 36 inches and was higher from March to September. During October there was but little difference in monthly means of the soil at the different depths, and the average of the soil was not far from the mean air temperature. The greatest difference between the monthly means of the air and that of the soil at 36 inches was in July, when the air averaged 15° warmer. In December, however, the soil at 36 inches averaged 14° warmer than the air.

In Table 2 are presented the highest and lowest temperatures of the air and of the soil at depths of 1 inch, 3, 6, 9, 12, 24, and 36 inches for each year of the five years 1900 to 1904, inclusive. These values were determined by considering the highest and the lowest reading each month as recorded from one daily reading of the thermometers.

TABLE 2.—Highest and lowest temperatures of the air and of the soil at depths of 1 inch, 3, 6, 9, 12, 24, and 36 inches for each year for 5 years, 1900 to 1904, inclusive, at Lincoln, Nebr., as determined by considering the highest and the lowest readings each month as recorded from one daily reading of the thermometers

	1900		1901		1902		1903		1904		For 5 years	
	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest
Air.....	94	2	102	-8	91	0	95	0	91	-6	102	-8
Soil:												
1 inch.....	102	19	120	12	91	20	95	21	96	20	120	12
3 inches.....	100	21	110	16	90	22	94	21	96	20	110	16
6 inches.....	93	22	102	19	87	25	89	23	90	22	102	19
9 inches.....	89	26	92	25	86	26	85	23	84	23	92	23
12 inches.....	81	28	86	27	78	28	80	24	79	23	86	23
24 inches.....	75	33	77	33	73	33	73	32	72	29	77	29
36 inches.....	71	35	73	36	76	35	70	34	69	32	76	32

It will be noted that the highest air temperature recorded was 102°. Readings as high as this, or higher, were recorded as deep in the soil as 6 inches, 120° being recorded at a depth of 1 inch; 110° at 3 inches, and 102° at 6 inches.<sup>1</sup> Below 6 inches the highest temperatures recorded was not as high as that recorded in the air, 92° being the highest observed at 9 inches; 86° at 12 inches; 77° at 24 inches; and 76° at 36 inches. These high readings were all made during July with the exception of the reading at 36 inches, which occurred in September.

The lowest air temperature recorded during the five years was 8° below zero, while at a depth of 1 inch in

the soil 12° was the lowest observed; at 3 inches, 16° was the lowest; at 6 inches, 19°; at 9 inches, 23°; at 12 inches, 23°; at 24 inches, 29°, and at 36 inches, 32°.

At a depth of 12 inches in the soil the last freezing temperature in spring was recorded in March and the first in autumn was recorded in December. At 24 inches freezing temperatures were recorded in one year in January; in two years in February; and in two years in March. At 36 inches freezing temperatures were recorded in only one year out of the five and then during only one period, from February 21 to March 7, 1904, when the thermometer read 32° each day for 16 consecutive days.

When unusually high or low temperatures were recorded in the air they would be recorded on the same day in the soil down to a depth of 6 inches. At 9 and 12 inches they were frequently recorded 24 to 48 hours later than in the air, and at 24 and 36 inches there would be no apparent indication of unusually high or low air temperatures.

The mean annual range, or the difference between the highest and the lowest readings observed each year, averaged for the five years, was greater in the air than in the soil, averaging 97° in the air and 84.2° in the soil at a depth of 1 inch. There was a decrease with increased soil depth, the decrease being greater in the upper layers, averaging 54.8° at 12 inches, or 29° lower than at 1 inch. From 12 inches downward to 36 inches the decrease was slower, averaging 42° at 24 inches and 37.4° at 36 inches.

The absolute range, or the difference between the highest reading and the lowest reading during the five years of observations, was 110° in the air, ranging from 102° to 8° below zero, while the absolute range in the soil at 1 inch was 108°, temperatures ranging from 120° to 12°. The absolute range, like the monthly range, decreased with increase in soil depth, being 63° at 12 inches, 48° at 24 inches, and 44° at 36 inches.

The mean variability of temperature, or the average change from day to day, was greater in the air than in the soil, averaging for the whole year roughly 50 per cent greater in the air than in the soil at a depth of 1 inch. There was a gradual decrease in variability of the soil from 1 inch, where it averaged between 4° and 5°, down to 36 inches, where it averaged less than half a degree.

Air temperatures showed the greatest variability in spring, early summer and early winter, and least in late summer and late winter, averaging nearly twice as great in April as in August.

Temperatures of the soil at all depths from 1 inch down to 36 inches showed the greatest variability in early summer and the least in winter. At 1 inch, daily changes in summer occasionally exceeded 10° and averaged about seven times greater than in winter. Changes from day to day were less frequent and smaller the deeper the soil, and at 36 inches the temperature was the same from day to day for a week or so at a time, and when changes did occur they seldom exceeded 1°.

<sup>1</sup> July, 1901, was an exceptionally warm month, the mean temperature averaging 8.6° above the normal.—Editor.